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Rethinking Construction Cost Overruns: Cognition, Learning and Estimation

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INTRODUCTION

Cost performance on a construction project remains one of the main measures of the success of a construction project (Atkinson, 1999; Chan and Chan, 2004). Reliable estimates are important for several reasons- for organisational budgeting purposes, for loan application if project has to be funded through credit facilities, to estimate their likely cost of financing loans (interest payments), for estimate commercial feasibility or viability of the project, etc. The present economic meltdown also imposes a parsimonious approach to spending on most organisations and governments. However, estimating the final cost of construction projects can be extremely difficult due to the complex web of cost influencing factors that need to be considered- type of project, material costs, likely design and scope changes, ground conditions, duration, size of project, type of client, tendering method- the list is endless (Ahiaga-Dagbui and Smith, 2012). Trying to work out the cost influence of most of these variables at the inception stage of a project where cost targets are set can be an exhaustive task, if not at all futile. Ignoring most of them altogether creates a perfect recipe for future cost overruns, disputes, law suits and even project termination in some cases. Even more, there is a high level of uncertainty around most of these factors at the initial stages of the project as noted by Jennings (2012).

Error! Reference source not found. shows major public projects that have experienced significant cost growth. Flyvbjerg *et al.* (2004) report that 9 out of 10 infrastructure projects overrun their budgets and that infrastructure projects have an 86% likelihood of exceeding their budgets. The on-going Edinburgh Trams project has already far exceeded its initial budget leading to significant scope reduction to curtail the ever-growing cost (Miller, 2011; Railnews, 2012). The recent 2012 London Olympics bid was awarded at circa £2.4 billion in 2005. This was adjusted to about £9.3 billion in 2007 after significant scope changes. The project was completed at £8.9 billion in 2010 (Gidson, 2012; NAO, 2012). These statistics have often led to extensive claims, disputes and lawsuits in some cases within the industry (Love *et al.*, 2010).

[Table 1 here]

Cost overrun in the construction industry has been attributed to a number of sources including technical error in design or estimation, managerial incompetency, risk and uncertainty to suspicions of foul play, deception and delusion, and even corruption. A recent debate on the Construction Network of Building Researchers (CNBR) on whether or not construction cost

overruns could be attributed to error in estimation or lies by project sponsors and estimators left many trailing questions than answers (See the November 2012 CNBR archive online) - How accurate or reliable can cost estimates be? What is the best measure of cost overrun? Might there be a need to change how cost performance is measured at present? Should the estimator be absolved of the responsibility of producing reasonably accurate estimates? Should the industry even bother about cost overruns at all if project goals are met in the long run?

While drawing on the works of some of the contemporary authorities on the subject, different schools of thought on causes of construction cost overruns have been synthesized in this paper to provide a coherent and holistic view of the problem. Recurring themes have been expanded upon, challenging traditional paradigms of assessing cost performance on construction projects while offering emerging frameworks of reckoning cost growth. It is proposed that there is a conflation of two quite different causes of cost growth: cost under-estimation and cost over-run. The paper then presents the development of cost model using data mining. It is hoped that data mining might be one of the possible avenues for alleviating the problem of project cost overruns within the construction.

SOURCES OF COST GROWTH

Causes of cost growth have been attributed to several sources including improperly managed risk and uncertainty (Okmen and Öztas, 2010), scope creep (Love *et al.*, 2011; Gil and Lundrigan, 2012), optimism bias (Lovallo and Kahneman, 2003; Jennings, 2012) to suspicions of foul-play and corruption (Wachs, 1990; Flyvbjerg, 2009). While not attempting to provide a definitive list of all possible sources, this section of the paper provides a synthesis of the mainstream arguments on the causes of cost growth, drawing particularly on the works of some of the contemporary authorities on the subject to provide a holistic view on the subject.

Risk and Uncertainty

The nature of a construction project makes it particularly prone to the effects of risk and uncertainty- its complex and dynamic; each project has many parties with business and project objectives; projects are exposed to the weather (not in a controlled environment), project duration typically spreads over several years before completion, etc. It is no surprise then that risk, simply defined here as the measure of exposure to financial loss, or gain

(Akintoye, 2000), has been heavily cited as one of the main causes of failure to meet cost targets on construction projects (Skitmore and Ng, 2003; Öztas, 2004; Okmen and Öztas, 2010). Arguably, the construction industry is perhaps one of the most risk prone industries with project cost being one of main areas susceptible to its effects. Almost all types of risk (including scope changes, inclement weather, unsuitable ground conditions, disputes, client's cash flow problems, etc) bear some form of financial ramifications.

As noted by Ahiaga-Dagbui and Smith (2012), effective cost planning relates the design of facilities to their cost, so that while taking full account of quality, risks, likely scope changes, utility and appearance, the cost of a project is planned to be within the economic limit of expenditure. This stage in a project life-cycle is particularly crucial as decisions made during the early stages of the development process carry more far-reaching economic consequences than the relatively limited decisions which can be made later in the process. Despite the great importance of cost estimation, it is undeniably not simple, nor straightforward, because of the lack of information in the early stages of the project (Hegazy, 2002). To achieve accuracy, the estimator has to be able to predict the future- something even the best technologies available cannot achieve with certainty, for accurate reasoning is only possible in a world where information is complete and certain, and where cause and effect links are accurately known. Risk and uncertainty thus deeply pervade the construction industry, and continue to cause unending controversy and debate because, as (Baccarini, 2005) suggests, all too often risks are either ignored or dealt with in a completely arbitrary way using some rules of thumb or percentages. As Flanagan and Norman (1993) point out, the task of risk management or response in most cases is thus so poorly performed that far too much risk is passively retained, ultimately resulting in cost escalation during project delivery.

Strategic Misrepresentation and Optimism Bias

Some contemporary authorities on the subject of cost overrun have proposed more depressing explanations to the phenomenon. Flyvbjerg *et al*, suggest that overruns are chiefly due to 'strategic misrepresentations', i.e. outright lying (Flyvbjerg *et al.*, 2002) and 'optimism bias' (Flyvbjerg, 2007). Flyvbjerg *et al.* compared the cost of projects at the time of the decision to build to the cost at completion and found inaccuracies in cost forecasts for transportation infrastructure projects to be on average 44.7% for rail, 33.8% for bridges and tunnels, 20.4% for roads and concluded that 9 out of 10 projects outrun their cost targets. Overruns beyond 100% of original cost are also not uncommon (Trost and Oberlander, 2003; Odeck, 2004).

In order to get the project approved, sponsors and estimators, especially on public works, tend to intentionally underestimate the true cost of the project in what has been described as the 'Machiavelli factor' (Flyvbjerg, 2003). 'By routinely overestimating benefits and underestimating costs, promoters make their projects look good on paper, which helps get them approved and built' (Flyvbjerg *et al.*, 2005). It makes little reasoning to stop the project once a considerable amount of money has already been spent to get it started, he claims (Flyvbjerg *et al.*, 2004). Wach (1989) was even more forthright in his paper '*When planners lie with numbers*' and later advocated for better ethics in forecasting for public works (Wachs, 1990).

If cost overruns cannot be explained by intentional underestimation, optimism bias might be a likely culprit according to Flyvbjerg (2007). Optimism bias can be explained as the cognitive disposition to evaluate future events in a fairer light than they might actually be in reality (Lovallo and Kahneman, 2003). Unlike strategic misrepresentation, this might not be born out of deceptive intent, but also often leads to underestimating true cost, overestimation of benefits and overlooking the potential of error and uncertainty. The potential gains of the project thus becomes overwhelmingly enticing, and almost blinding to likely pitfalls. It also leads to underestimating the full extent of certain risk events, should they occur.

In effect, delusion and deception are complementary explanations of the failure of large infrastructure projects, causing works such as diverting existing utilities, environmental impacts and foreseeable risks to be continually underestimated in construction (Flyvbjerg, 2009). This line of diagnosis of the problem of cost overrun might seem appealing, at least on first thought, especially in terms of large capital intensive public projects or those that are likely to make to make high political statements. Flyvbjerg's far-reaching work on cost overruns led to the endorsement of his 'Reference Class Forecasting' by the American Planning Association in 2005 (cf. APA, 2005; Flyvbjerg, 2007). This will be discussed in more detail in later sections of the paper.

Going beyond Strategic Misrepresentation and Optimism Bias

Even though the deception and delusion might be plausible explanations for cost overruns, particularly in large publicly funded or politically motivated projects, they are not easily generalisable to all types of projects undertaken within the construction industry. Researchers, including Love (2012), rebut Flyvbjerg's conclusions as simplistic, largely misleading and not an accurate reflection of reality. Love *et al.*'s rejoinder suggest a move

beyond optimism bias and strategic misrepresentation to focus on intermediary events, actions, the so-called ‘pathogens’ that occur between project inception and completion. At the core of Love’s argument is that many events and actions that are not accounted for in the initial estimates tend to drive up cost. This school of thought is largely supported by Aibinu and Pasco (2008), Odeck (2004) and Odeyinka *et al* (2012). Love’s case study of social infrastructure projects suggest that foul-play, as suggested by Flyvbjerg and Wach, might not be best explanations of cost overruns and that the fingers point at the events that occur before and during project delivery stage (Love *et al.*, 2011). Besides, it is almost impossible to draw valid distinctions along a continuum of motivation when promoting a project from reasonable optimism, through over-enthusiasm, culpable error to deliberate deceit using statistical analysis, as adopted in the Flyvbjerg’s works.

Research on leadership and governance on construction projects by Gil and Lundrigan (2012), provide perhaps a more holistic assessment of cost growth that aligns closely with the views of Love, *et al* above. Projects evolve, is essentially the core of their defence. Very often, construction projects change considerably in scope and design between conception, to inception and completion often due to a client’s proposed changes or technically imposed changes. This suggests that it might be erroneous to simply compare the cost of a project at inception, A, with the cost at completion, B, and wherever $B > A$, then overruns have occurred and estimators of A either lied or are incompetent- A and B are essentially very different. More robust explanations of overruns need to factor in process and product, as well as sources of changes to scope. For Love and Gil *et al*, project overruns are not really a case of projects not going according to plan (budget), but the other way round- plans not going according to project.

Gil and Lundrigan propose a ‘relay race’ framework for understanding cost growth, particularly on mega projects such as the London Olympics Project, Scottish Parliament or Terminal 2 project at the Heathrow Airport, all of which seemed to have suffered the curse of cost growth, at least on a perfunctory examination. In the relay race of construction delivery, the baton of project leadership is passed on from one person(s) or organisation at the different stages of the project delivery. The aims and scope of the project, as well as skills and competencies of the project sponsors and promoters (project governors) at the conceptual stage of the project are often very different from their counterparts at the project design or delivery stage. Also, it is not unusual for most public projects to have long gestation periods,

stretching over several years, before final approval is reached, by which time project budget would also have changed a number of times. The Scottish Parliament Building is a paragon in this respect- the *circa* £40 million submitted by the Scottish Office as likely final cost did not take into consideration project location or the building of a completely new parliament building. It is no wonder the final cost of the project was 10 times this initial proposed cost (Fraser, 2004).

Perception and Measuring Overruns

Perhaps our perception of cost overruns needs to change altogether. What is described as cost overruns at the moment might not be overruns after all if reckoned through the eyes of different procurement routes, for examples. It is possibly one of the reasons why cost overrun is not often reported in projects procured through joint ventures or alliancing. Typically, in traditional contracting, design and estimates are first prepared by the Client's Estimator (CE) and then bids are invited from contractors. The lowest bidder often wins the job with the lowest tender value becoming the cost estimate at the beginning of the project (A). The contractor undertakes then to deliver the project at cost, A, and all add-ons are dealt with through change orders or claims until project completion at cost, B. Whenever $B > A$, overruns are reported. It is easy to identify how competition, market conditions, optimism bias and the selection by lowest bidder combine to drive down the initial estimate, A, creating a somewhat unrealistic target as likely final cost. For the contractor therefore, winning work at the right price (realistic cost) becomes a very difficult task. To be thorough in estimation would mean including likely cost of most/all risk events in the tender, consequently pricing himself out of competition. Most contractors may therefore not include potential risk events in their tenders so as to increase their likelihood of winning the contract. This was evident in related studies in modelling final cost of construction projects (Ahiaga-Dagbui and Smith, 2012).

Some have suggested that the industry move beyond its fixation on measuring project success largely in terms of cost (Bassioni *et al.*, 2004; Yeung *et al.*, 2008). The CNBR debate was frequently punctuated by the question, 'why care about cost overruns anyway? If projects run over budget but deliver what the client wants, shouldn't everyone be happy?' After all, cost overruns only represent our human inability to predict future events accurately, or identify risks and quantify their likely impact and cost. Others think perhaps there is a need for a paradigm shift in how projects are evaluated to cover a combination of social, economic, social, usability, value for money, etc. (Toor and Ogunlana, 2010). The Sydney Opera House

experienced large overruns at the time of construction but its now generally considered a 21st century icon of buildings and a popular destination for tourists and opera concerts. Similarly, in spite of the controversies about cost overruns, the Scottish Parliament Building has won several awards, including the coveted Stirling Award in 2005 by the Royal Institute of British Architects for its audacious, highly conceptual and iconic design. Even if cost should be a major factor for assessment, it certainly should not be a simplistic or statistical comparison between awarded contract sum and cost at final accounts.

Cognition, Bias and Learning

Can a science that combines intuition and analysis ever be precise or unbiased? A qualified ‘no’ is probably the answer to that question, according to Kahneman and Tversky (1979), formulators of Prospect Theory- decision making under risk and uncertainty. The theory suggests people make decisions based on the likely gains, or loss, of a venture, and not necessarily based on the real outcome of the decision. It further proposes that decision making is often flawed by systematic biases and that error in judgement is often systematic and predictable, rather than random. Kahneman, a Noble Prize winner for his works on decision making and behavioural economics, delineates decision making and the illusion of understanding, stating that we often exhibit an excessive confidence in what we believe we know about any situation, and that our inability to acknowledge the full extent of our ignorance and the uncertainty of the world we live in makes us prone to overestimate how much we understand (Kahneman, 2011). His work with Lovallo (2003) provides further defence of the Prospect Theory from different business areas. Kahneman’s theory holds profound extensions for decision making in the construction industry, especially for large public projects where the effects and cost of risk and uncertainty are particular heightened. It would also provide large support of Flyvbjerg’s arguments on strategic misrepresentation and optimism bias already discussed in this paper. Conceivably, this is one reason why it is easy to err on the side of optimism when promoting a project, or when estimating the outcome of a risk event.

Perhaps even more controversial are the conclusions reached by Dunning and Kruger (2009), that incompetence does not only cause poor performance but also has the dual effect of robbing people of the ability to recognise poor performance. They posit that the metacognitive skills required to judge the accuracy of a decision is the same required to evaluate the error in the same decision- to lack the former, is to fall short in the latter as well

(Kruger and Dunning, 1999). The result thereof is that the ‘incompetent will tend to grossly overestimate their skills and abilities’ (Kruger and Dunning, 2009). They tied their conclusion to Darwin’s pronouncement- ‘ignorance more frequently begets confidence than does knowledge’ (Darwin, 1871), a theory largely supported by Ehrlinger *et al.* (2008) and Maki *et al.* (1994).

Herein lies the estimation complex- a combination of optimism bias and prospect theory predisposes us to underestimate true cost, discounting the real effect of uncertainty and error while doing so. At the same time, Dunning-Kruger tendencies blind forecasters to the error in reaching unrealistic estimates for project cost. Juxtapose these with the effect of risk and uncertainty, competition embedded within the culture of lowest-bidder tendering, as well as strategic misrepresentation, and the overruns reported in Tables 1 and 2 become less surprising. It is easier to understand how most cost estimates can be prepared, or at least reported, with an unjustifiable confidence in their accuracy. If this is the case, then perhaps we might not have to move beyond optimism bias just yet, as suggested by Love (2011). If we are indeed systematically prone to err towards optimism bias in our reasoning, then it might be wise to rethink how that affects our estimates and what needs to be done about it.

Flyvbjerg (2002) also noted that ‘no learning’ seemed to be taking place in the construction industry over the 70 years prior to his study, and that estimation accuracy has not seen much improvement even with the advancements in technology and the proliferation of cost models and project management approaches. Kruger and Dunning (2009), as well as Ehrlinger *et al* (2008) attribute lack of performance improvement to the lack of accurate and constructive feedback. They however observed that an awareness of limitations of skills and decision making within an environment of uncertainty, helped to improve performance and self-calibration. A lack of learning in the construction industry could be explained in a number of ways- that the mitigating factors causing overruns are ones that the industry absolutely cannot overcome and therefore has to accept cost overruns as normal part of practice; or that there is simply very little incentive to reach realistic target inception; or further still that the industry seems to largely miss the opportunities offered by effective knowledge transfer and feedback from previously completed projects, as noted by Hartmann and Dorée (2013). How is explicit and tacit knowledge captured and utilised within the industry presently? How do project closure reports feed back into the development of new projects for continuous improvement?

RETHINKING OVERRUNS

For the purposes of cost modelling or estimation, it is important to clarify an important point. Existing literature, and recent CNBR debate, on ‘cost overruns’ seems to conflate two related, but different issues- overruns and underestimation. Unfortunately, a lot of cost models do not make this distinction either and thus become limited in their application in practice. As already pointed out, most large publicly funded projects tend to go through a long gestation period after project conception during which many changes to scope and accompanying costs occur- sometimes the initial scheme bears little likeness to the defined project. The estimated cost at project inception often fails to take into consideration a lot of details and information, largely because much of these are not yet available or uncertain- the case of the initial circa £40 million estimate for the Scottish Parliament. For many large publicly funded projects, this is normally when project sponsors garner for project approval and funding. It is perhaps at this stage the effects of Prospect Theory, Dunning-Kruger effect, Optimism bias and strategic misrepresentation are particular heightened to keep cost at an attractive low and benefits of undertaking the project high. This might be what accounts for what the authors refer to as underestimation of likely cost- the difference between estimated cost at project inception and cost at the end of project definition phase in Error! Reference source not found..

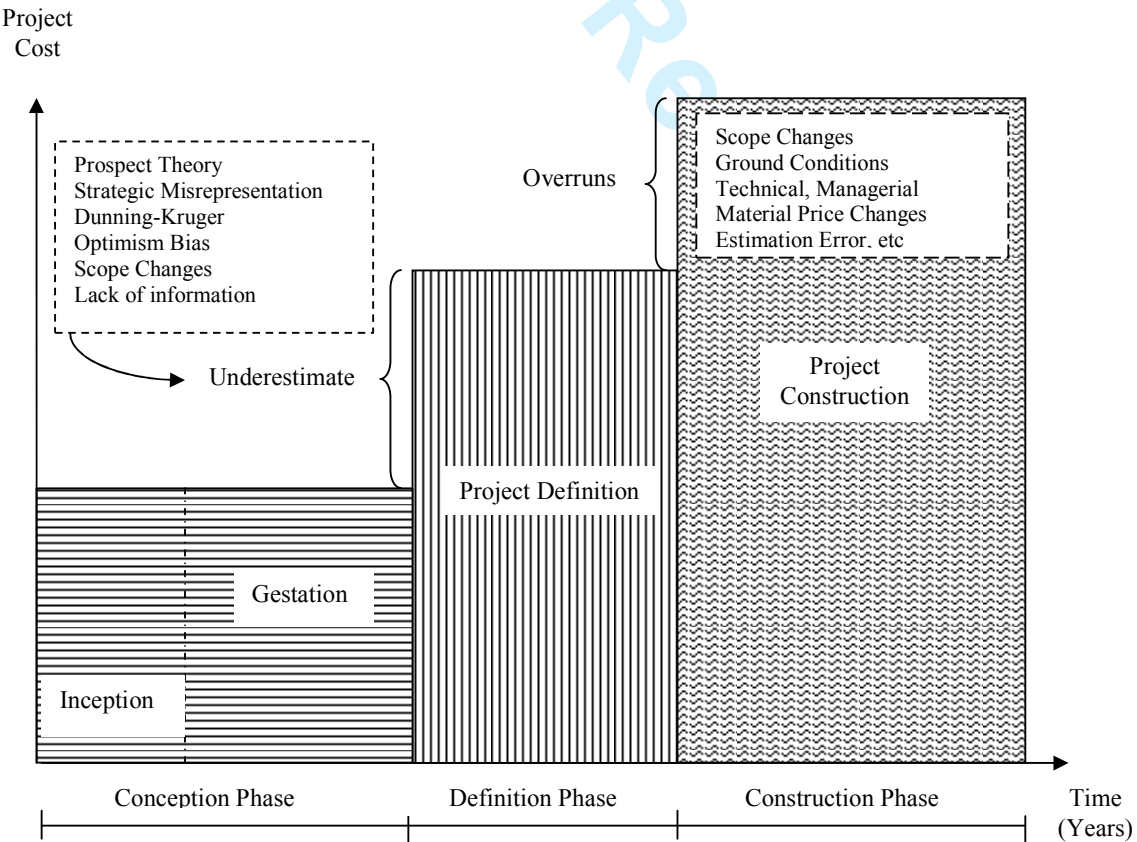


Figure 1: Conceptual model for understanding cost growth on large public projects.

Overruns however, are aptly described as the difference in cost at project completion and project definition stage (see **Error! Reference source not found.**). This is usually as a result of further scope changes, normally not as significant as those at project definition stage, ground conditions, technical and managerial difficulties, material or labour price changes, estimation error, etc. This are the factors that Love *et al* (2011) describe as ‘pathogens’. So, whereas, Flyvbjerg’s work mainly deals with underestimation, Love’s explanations for cost growth largely covers the latter phases of the construction project. It is important to note however that **Error! Reference source not found.** is not necessarily wholly applicable for small, non-political and routine projects where the effects of the political and cognitive causes of cost growth are less heightened. Much of the media hype on cost overruns however is often based on a comparison between cost at inception and cost at completion, almost ignoring the mediating phases of project gestation and definition.

REFERENCE CLASS FORECASTING

Flyvbjerg developed a practical method for forecasting cost of large projects based on Reference Class Forecasting (RCF) formulated by Kahneman and Tversky (1979; 1994). RCF attempts to use ‘distributional information’ (knowledge) from previous projects similar to the new project being undertaken, the so-called taking of an ‘outside view’ of planned actions, based on actual past performance. Kahneman and Flyvbjerg reckon this approach might somehow help to bypass optimism bias and strategic misrepresentation in decision making (Flyvbjerg, 2007). The methodology involves three steps, summarised simply here as:

- a. Identify a reference class of past, similar projects.
- b. Estimate a probability distribution for the selected reference class, and
- c. Establish likely cost of the new project using the reference class distribution.

The first instance of its application was on Edinburgh Tram project by the UK Government—the original forecast by the Transport Initiatives Edinburgh (tie), the project promoter was about £255 million but the RCF indicated this could rise up to £400 million and warned that the final cost could even be exceedingly higher (Flyvbjerg, 2007). Recent estimates now indicate that the final construction cost of the Trams could be around £776 million (Miller, 2011; Railnews, 2012). The RCF has reportedly been applied to the £15 billion London Crossrail and £7.5 million Taunton Third Way projects in the UK (Flyvbjerg, 2007).

Even though RCF is still yet to be widely tested, or even adopted, it might be a good step in the right direction especially in dealing with the root causes of *underestimation*, (as opposed to cost overrun) as shown in **Error! Reference source not found.**, i.e. optimism bias, Prospect Theory, Dunning-Kruger effect and strategic misrepresentation. However, as pointed out by Flyvbjerg, RCF is largely applicable to large, non-routine or one-off projects such as stadiums, museums, dams, etc. On smaller, less political, or frequent projects however, a fairly similar but more established method of forecasting that employs previous experience and incremental learning is data mining. It has been extensively used in other industries including finance (Kovalerchuk and Vityaev, 2000), medicine (Bellazzi and Zupan, 2008; Koh and Tan, 2011) and business (Apte *et al.*, 2002), but yet to see widespread application in the construction industry. Notwithstanding, it has been applied to construction knowledge management (Yu and Lin, 2006), estimating the productivity of construction equipment (Yang *et al.*, 2003), study of occupational injuries (Cheng *et al.*, 2012a), alternative dispute resolution (Fan and Li, in press) and prediction of the compressive strength high performance concrete (Cheng *et al.*, 2012b) in the construction industry. It has been used to develop final cost models in the next section of this paper, in a manner that addresses the *overruns* part of **Error! Reference source not found.**

FINAL COST MODEL DEVELOPMENT USING DATA MINING

Data mining is the analytic process for exploring large amounts of data in search of consistent patterns, correlations and/or systematic relationships between variables, and to then validate the findings by applying the detected patterns to new subsets of data (StatSoft Inc, 2008). Data mining attempts to scour databases to discover hidden patterns and relationships in order to find predictive information for business improvement. Similar to reference class forecasting, data mining starts with the selection of relevant data from a data warehouse that contains information on organisation and business transactions of the firm (Ngai *et al.*, 2009). The selected data set is then pre-processed before actual data mining commences. Data pre-processing typically involves steps such as sub-sampling, clustering, transformation, de-noising, normalisation or feature extraction (StatSoft Inc., 2011) to ensure that the data are structured and presented to the model in the most suitable way for effective modelling.

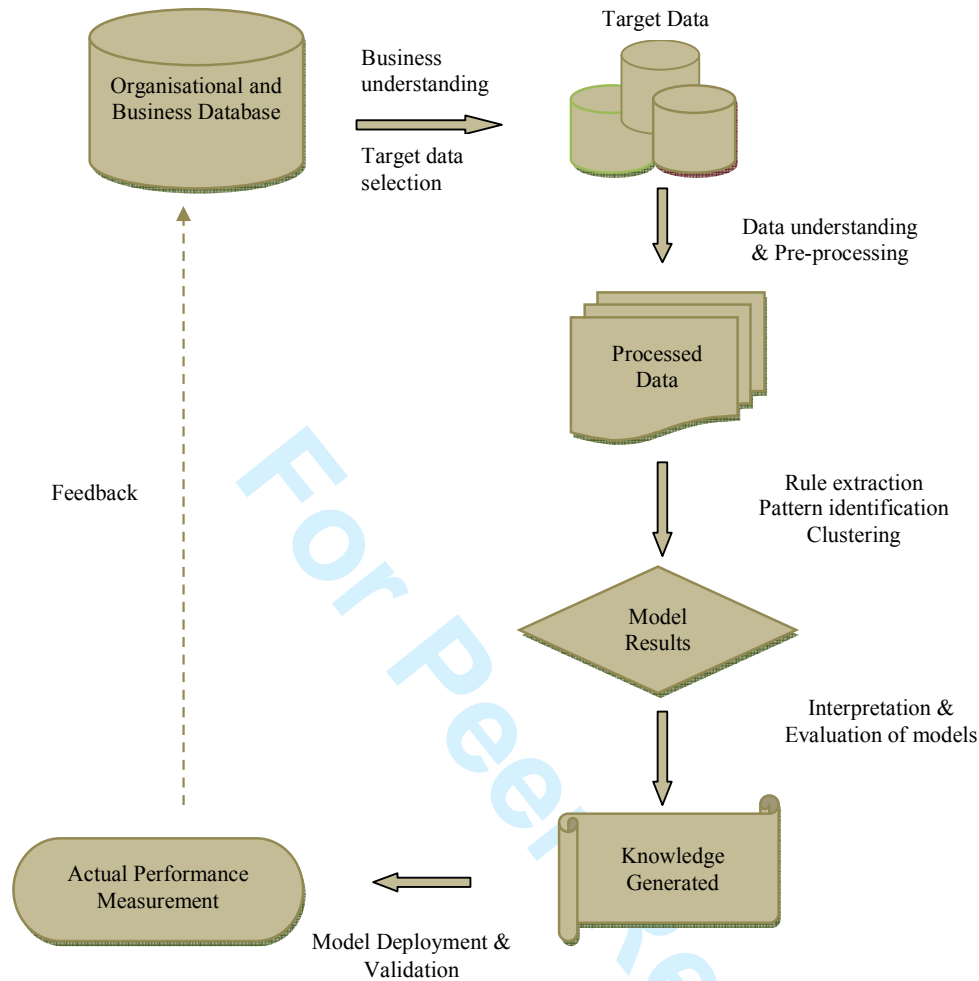


Figure 2: The generic data mining process

The next stage, as shown in Figure 2, involves the actual modelling, where one or a combination of data mining techniques is applied to scour down the dataset to extract useful knowledge. The results obtained are then evaluated and presented into some meaningful form to aid business decision making. This final step might involve graphical representation or visualisation of the model for easy communication. Artificial neural networks (ANN) is used for the modelling aspect of this paper mainly because of its learning and generalisation capabilities (Anderson, 1995).

Data

The data used for the models in this paper were supplied by an industry partner with its primary operation in the delivery of water infrastructure and utility in the UK. Approximately 1600 projects completed between 2004 and 2012, with cost range of between £4000 - £15 million, comprising newly built, upgrade, repair or refurbishment projects were used for the

models reported in this paper. 15 project cases were selected using stratified random sampling to be used for independent testing of the final models. The remaining data were then split in an 80:20% ratio for training and testing of the models, respectively.

Cost values were normalised to a 2012 baseline with base year 2000 using the infrastructure resources cost indices by the Building Cost Information Services (BCIS, 2012). Numerical predictors were further standardized to *zScores* using

$$zScore = \frac{x_i - \mu}{\sigma} \qquad \text{Equation 1}$$

where: *zScore* is the standardized value of a numerical input, x_i
 μ is the mean of the numerical predictor
 σ is the standard deviation of the numerical predictor

This allowed numerical inputs to be squashed into a smaller range of variability, potentially improving the numerical condition of the optimization process of the model (StatSoft Inc, 2008). If one input has a range of 0 to 1, while another has a range of 0 to 30 million, as was the case in the data that were used in this analysis, the neural net will expend most of its effort learning the second input to the possible exclusion of the first. All categorical variables were coded using a binary coding system. Data screening using scree test, factor analysis and optimal binning allowed for the selection of six initial predictors (primary purpose of project, project scope, project delivery partners, operating region, project duration, and initial estimated cost) to be used for the actual modelling using ANN. See Ahiaga-Dagbui and Smith (2013) for more details on the data, predictor selection and data pre-processing used in this paper.

Model Development

The final model was developed after an iterative process of fine-tuning the network parameters and/or inputs until acceptable error levels were achieved or when the model showed no further improvement. First, the automatic network search function of Statistica 10 software was used to optimise the search for the best network parameters, after which customized networks were developed using the optimal parameters identified. 5 activation functions¹ were used at this stage in both hidden and output layers, training 2000 multi-layer perceptron networks and retaining the 5 best for further analysis. The overall network

¹ identity, logistic, tanh, exponential and sine activation functions

performance was measured using the correlation coefficient between predicted and output values as well as the Sum of Squares (SOS) of errors. SOS is defined here as:

$$SOS = \sum(T_i - O_i)^2 \dots\dots\text{Equation 2}$$

Where O_i is the predicted final cost of the i th data case (Output)
 T_i is the actual final cost of the i th data case (Target).

The higher the SOS value, the poorer the network at generalisation, whereas the higher the correlation coefficient, the better the network. The p -values of the correlation coefficients were also computed to measure their statistical significance. The higher the p -value, the less reliable the observed correlations. The retained networks are then validated using the 15 separate projects that were selected using stratified sampling at the beginning of the modelling exercise. See Figure 3 for the overall performance of 7 of the retained networks.

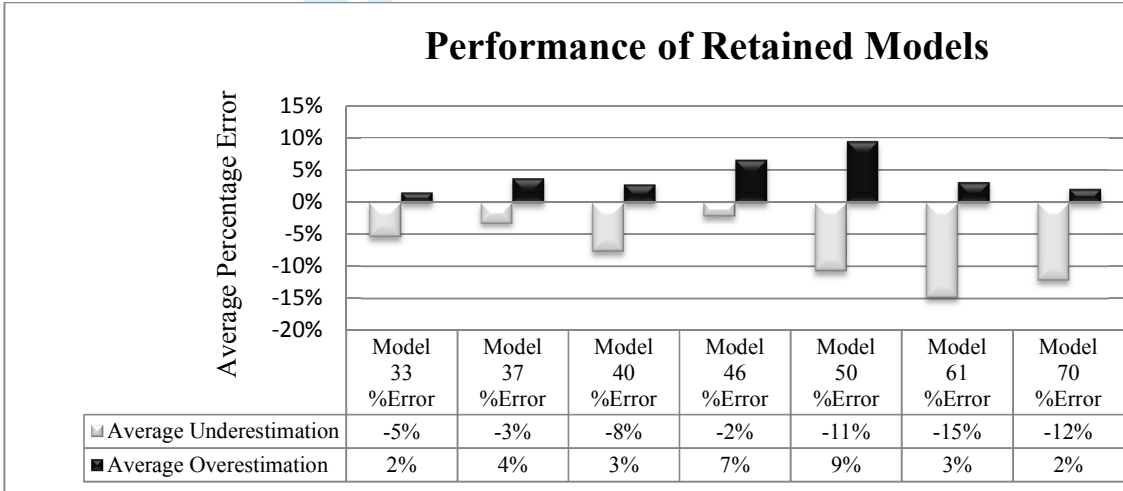


Figure 3: Performance of selected models

[Table 2 here]

Error! Reference source not found. shows the predictions and absolute percentage errors (APE) achieved by the best model (model 33). The average APE achieved by this model was 3.67% across the 15 validation cases. Its APEs ranged between 0.04% and 15.85%. It was observed that the worst performances of the model were achieved on projects with the smallest values in the validation set (cases 13 & 15). This might potentially be because a majority of the projects used for the model training had values in excess of £5 million. However, the actual monetary errors on these predictions were deemed satisfactory as they were relatively small

(about £3500 & £2500 for models 13 & 15 respectively). 87% of the validation predictions of the best model were within $\pm 5\%$ of the actual cost of the project. The authors are now exploring avenues of transforming the models into standalone desktop applications for deployment within the operations of the industry partner that collaborated in this research.

CONCLUSION

Cost estimate reliability and accuracy on construction projects continues to receive a lot of attention from both industry and academia. The industry is faced with a complex web of causes, which we propose fall into two distinct yet often conflated categories – cost underestimation and cost overrun:

Underestimation:

- Optimism Bias- a propensity to believe and act on a notion that all will go well leading to the underestimation the role of uncertainty in outcomes;
- Prospect Theory- making decisions based on likely gains and loss rather than the actual outcome of the decision;
- Strategic misrepresentation- outright lying and corruption;
- Dunning-Kruger effect- the bend to overestimate competency or accuracy in judgement and the inability to see past our own errors; competition to win projects;

Overrun:

- Scope changes, whether mandated by circumstances or requested by client.
- Managerial and technical difficulties.
- Risk and uncertainty
- Ground conditions, price changes, etc.

Most of these, especially the cognitive and psychological factors, tend to work together to drive down the true cost of the project during the initial stages, creating a false and unreliable estimate as target to reach. We have attempted to provide a holistic view of the problem of cost growth, while presenting a conceptual model to distinguish between these often conflated ideas of underestimation and overruns on construction projects. Reference Class Forecasting was discussed as a possible means of addressing underestimation, particularly on large publicly funded projects. The development of a final cost prediction model using data mining and artificial neural networks was then presented as a possible avenue of addressing cost overruns in the construction industry. The best model achieved an average absolute percentage error of 3.67% with 87% of the validation predictions falling within an error range of $\pm 5\%$. These methods can be used to develop decision support systems especially at early

stages of the construction project as well as complement traditional methods of estimation in order to reach more accurate and reliable cost estimates.

Clients can play a crucial role in ensuring the quality and reliability of cost estimates in the construction industry. As indicated by the Commercial Manager of one of the biggest construction companies in the UK, 'winning a tender is easy. But winning at the right price is difficult.' Unless clients start demanding *realistic* estimates, rather than the lowest estimates at the early stages of a project, the problem of cost overrun might remain with the industry for a long time to come. Cultural changes within the industry towards the search for realistic targets might incentivise contractors to flag up potential estimating pitfalls early-on. Questions about who has the responsibility on behalf of the client to govern the project always has profound implications on cost growth from inception to completion and needs to be addressed very early on a project. This is particularly important on mega projects such as the London 2012 Olympic Project or the Scottish Parliament (see the 'Holyrood Enquiry' (Fraser, 2004) and 'Design by Deception' (Flyvbjerg, 2005) for the interactions between project leadership, politics, and business and cost growth on the Scottish Parliament Building and Sydney Opera House respectively.

Project knowledge capture and its utilisation would also be very crucial in tackling cost overruns. Some data mining techniques like neural networks are particularly useful in modelling both explicit and tacit knowledge within extensive databases. This can be used to complement traditional cost estimation methods or RFC to reach more realistic and reliable estimates. Finally, and perhaps even more importantly, is the creation of a culture of critical questioning, measures of accountability, with checks and balances to make sure that cost is managed to be within reasonable budget limits.

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For Peer Review

Tables

Table 1: Some Examples of Cost Growth in Construction Projects

<i>Project</i>	<i>Estimated Cost</i>	<i>Final Cost</i>	<i>% Overrun</i>
Sydney Opera House	AUD 7	AUD 102	1357
Nat West Tower	£15	£115	667
Thames Barrier Project	£23	£461	1904
Scottish Parliament	£195*	£414	112
British Library	£142	£511	260

*September 2000 estimate. Initially stated cost was about £40 million Source: Audit Scotland (2004)

Table 2: Validation results of the best model (Model 33)

<i>Validation Case</i>	<i>Actual Final Cost</i>	<i>Final Cost predicted</i>	<i>Model Error</i>	<i>Model Absolute % Error</i>
1	£ 4,912,649	£ 5,120,943	-£ 208,294	4.24%
2	£ 1,617,225	£ 1,617,805	-£ 580	0.04%
3	£ 11,277,470	£ 10,743,624	£ 533,846	4.73%
4	£ 2,110,260	£ 2,136,125	-£ 25,865	1.23%
5	£ 5,398,965	£ 5,425,142	-£ 26,177	0.48%
6	£ 180,532	£ 181,214	-£ 681	0.38%
7	£ 2,572,564	£ 2,530,178	£ 42,386	1.65%
8	£ 1,440,593	£ 1,372,864	£ 67,729	4.70%
9	£ 3,842,258	£ 3,793,851	£ 48,407	1.26%
10	£ 4,194,219	£ 4,131,285	£ 62,934	1.50%
11	£ 375,170	£ 387,731	-£ 12,561	3.35%
12	£ 50,637	£ 51,502	-£ 865	1.71%
13	£ 24,479	£ 22,017	£ 2,462	10.06%
14	£ 858,112	£ 824,334	£ 33,779	3.94%
15	£ 21,798	£ 18,344	£ 3,454	15.85%
Average Absolute % Error				3.67%